Suspended Integrated Strip-line Transition Design for Highly Integrated Radar Systems

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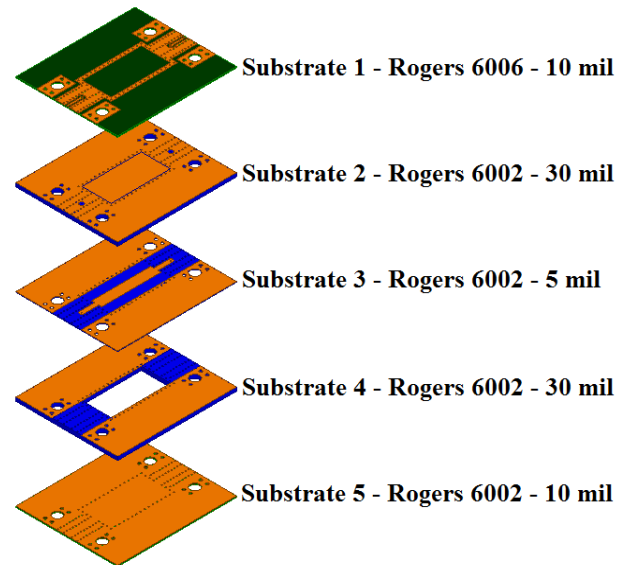University of Oklahoma
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Abstract: *A new transition method for realizing suspended substrate strip-line (SSS) components into multi-layer circuit boards is presented. This approach utilizes an optimized coplanar waveguide to strip-line vertical via transition prior to a strip-line to SSS transition. A DC-20 GHz suspended integrated strip-line (SISL) thru is designed, simulated, and measured to provide an ultra-wideband (UWB) proof-of-concept for this technology. The measured results show good correlation to the simulated results with a return loss and insertion loss of less than 10 dB and greater than 3.0 dB, respectively across the 20 GHz passband.*

Keywords: Coplanar Waveguide (CPW); Printed Circuit Board (PCB); Suspended Substrate Strip-line (SSS); Suspended Integrated Strip-line (SISL) RF packaging; Ultra-wideband (UWB).

Introduction

The next generation of highly integrated radar systems will continue to demand smaller form factors while improving radar performance. Critical radar parameters such as sensitivity and signal-to-noise/signal-to-jamming ratio can be improved by providing low loss filtering with steep roll-offs and large stop band attenuation at the receiver input. Traditionally, this has been accomplished using board integrated micro-strip and strip-line filtering [1]-[4]. While these filters are relatively easy to design and manufacture, they are notorious for being lossy and bandwidth limited. Also, to achieve sharp roll-offs, high order filters are needed, which can consume precious circuit board real-estate. A different and mechanically more complex approach is based on using suspended substrate strip-line (SSS) structures [5]-[7]. This technology allows for significant bandwidth improvement as well as low loss, steep roll-offs, and large out of band attenuation, while being inexpensive, and smaller than its predecessors.

However, due to the necessary metal cavity structure, SSS filters have been limited to connectorized packaging, with field-replaceable connectors. This does not align well with the trend of reducing size, weight, and power (SWaP) in modern and/or future system development. Identifying the need to use these filters in an integrated fashion, techniques have been investigated to embed the metal cavity within the
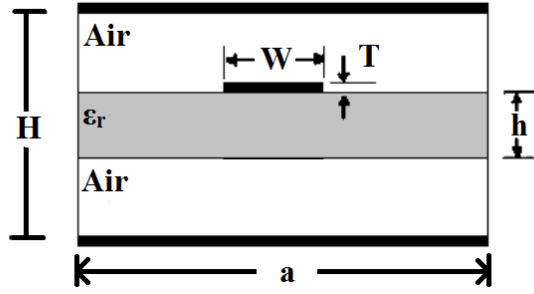

Figure 1. Layer by layer 3D-view of the thru board stack-up.

board stack-up; thus, eliminating the need for bulky connectors and allowing filter integration.

In this paper, the design and implementation of a new transition from coplanar waveguide with ground (CPWG) to suspended integrated strip-line (SISL) is presented. To verify the feasibility of the transition, a DC-20 GHz SISL thru is designed, simulated, and measured. An exploded layer-by-layer 3-D view of the thru structure can be seen in Fig. 1.

SSS Integration

Traditional SSS is accomplished by suspending a thin substrate of thickness h inside of a metal cavity with height H as shown in Fig. 2. An RF pin with a Teflon shield is placed through the metal side wall and soldered to the component, and then a field-replaceable edge launch connector is attached to the metal cavity. More recently, approaches have been taken to integrate SSS designs by implementing a single sided air gap SSS design [8] or attaching a metal structure above the SSS component and extending the circuit board [9], but none of them achieve a truly integrated component. The latest technique, shown in
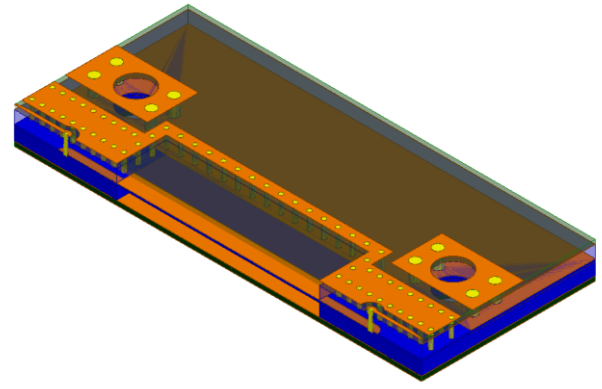
Figure 2. Suspended substrate strip-line side-view.

[10], delivers a more desirable integrated design, but the method for exciting the CPW trace eliminates the use of valuable top-copper real estate and is significantly more difficult from a fabrication and mechanical point-of-view. In our design the metal cavity is realized inside of a multi-layer circuit board stack-up by utilizing strategically placed, internal, air pockets with ground planes above and below the structure. To create the side-wall capacitance to ground, and keep the fields bound to the SISL structure, metallized vias were placed along the air pocket boundary with $\lambda/20$ spacing at the highest frequency of interest (20 GHz). These features can be seen in Fig. 3. By using the above techniques to integrate the structure, no modifications had to be made to the original connectorized metal cavity design. Therefore, design equations derived for the traditional SSS character-istic impedance and width can be used for SISL reducing the complexity of transitioning from SSS to SISL.
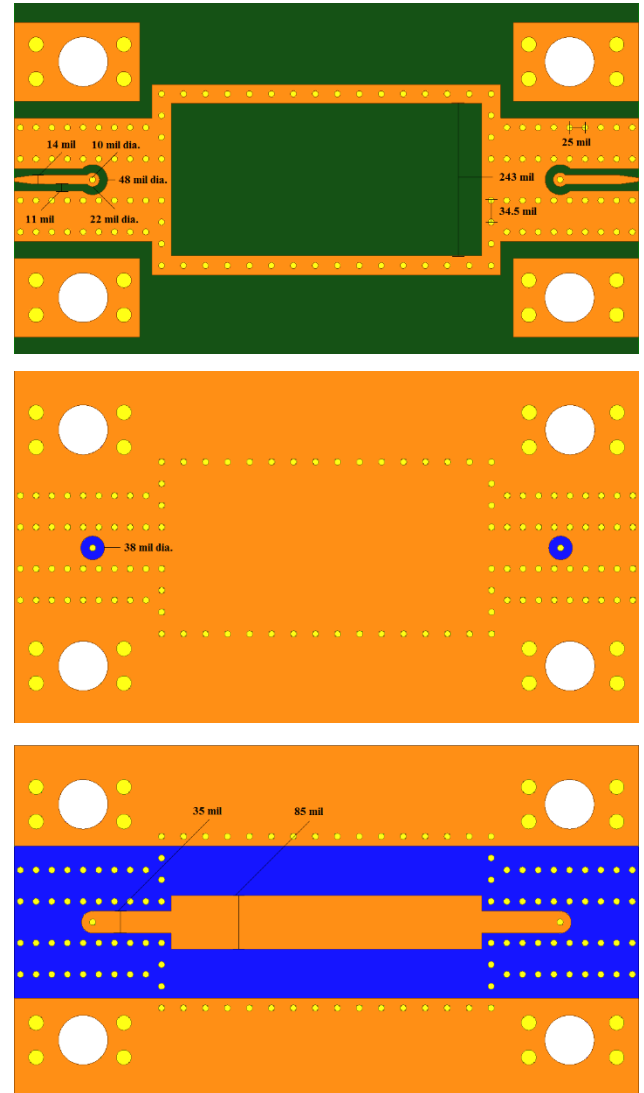
Edge launch or surface mount connectors are used to bring the signal to a top-layer board and exciting a coplanar waveguide trace. The signal then goes through a CPW-to-strip-line vertical via transition that is connected to the thru layer. Finally, a strip-line-to-SISL transition is implemented to ensure good matching throughout the frequency range. The signal is then brought back to the top-layer through another vertical via transition, where the signal is then fed into another edge launch connector for measurement purposes. In a more advanced PCB, the input and output CPW trace of an embedded SISL component would connect to the rest of the circuitry located on the top-layer.

SISL Design
The SISL thru is designed in a five-layer PCB board stack-up consisting of Rogers laminate materials. The first and fifth substrate layer are 10-mil-thick Rogers 6006 material. The second and fourth substrate layers are 30-mil-thick Rogers 6002 material. Lastly, the third substrate layer (Thru layer) is 5-mil-thick Rogers 6002 material. All substrate layers are clad with 0.5 oz. copper. The 6002 material is chosen due to its standard 5 mil thickness as well as low dielectric constant, which are desirable for SISL design.
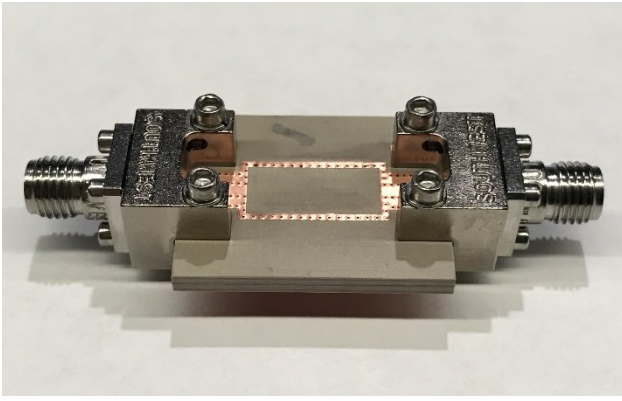

Figure 3. Internal-view of SISL thru structure.

Figure 4. Top-view of trace and transition layers.

The CPW, strip-line, and SISL thru traces were all modeled in Keysight's Advanced Design System (ADS) software and optimized in Ansoft's High Frequency Structural

50

Figure 5. Fabricated thru line structure.

Figure 6. Simulated vs measured transmission coefficient.

Figure 7. Simulated vs measured reflection coefficient.

Simulator (HFSS) software independently to tune for optimal performance. Then the individual designs were then brought together and the vertical via transition was added to the design. The via diameter, via pad, and anti-pads on copper layers 1 and 2 were all tuned to emulate a 50 ohm coaxial transmission to the thru layer. The final CPW trace width is 14 mil with a gap width of 11 mil. The strip-line and SISL trace widths were tuned to 35 and 85 mil, respectively. The via spacing along the CPWG trace is 25 mil and placed one via diameter away from the gap edge. The via spacing along the SISL air gap was increased to 35 mil to reduce the number of vias while still providing the necessary ground wall. If the spacing between vias becomes too large, the fields can flow beyond the intended side-wall resulting in less than desirable performance. Lastly, the length of the entire board was 1" with the SISL trace being 0.5" and both the CPW and strip-line lengths being 0.25" each. Fig. 4 gives a zoomed-in top-view of the top three copper layers to illustrate the design.
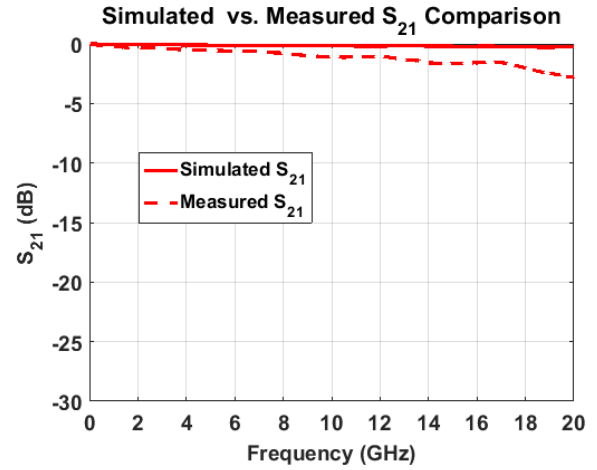
Another detail to keep in mind when designing the air gap, is keeping the width of the air gap to a minimum. When designing SISL components at either large bandwidths or at high frequencies, the air cavity must be narrow enough such that the propagation of parasitic waveguide modes within the pass-band is prevented. This so-called cut-off frequency is expressed as

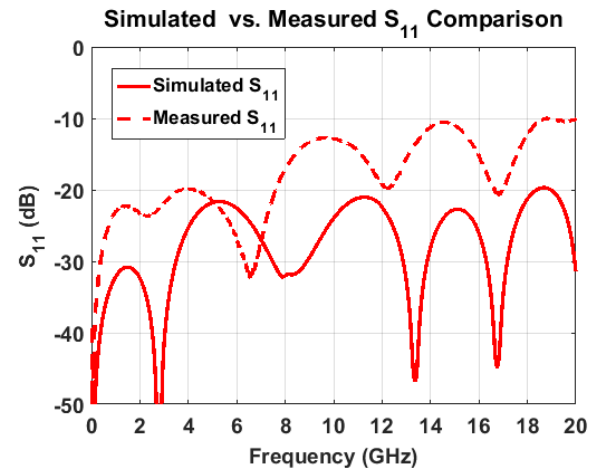$$ f_c = \frac{c}{2a} \sqrt{1 - \frac{h}{H}\frac{\varepsilon_r - 1}{\varepsilon_r}} , \qquad (1) $$

where a is the cavity width, h is the thickness of substrate 3, H is the cavity height, and ε_r is the dielectric constant of substrate 3, and $c = 3 \times 10^8$ m/s [10]. The cut-off frequency for the design shown in Fig. 1 is calculated to be 23.5 GHz. Therefore, any undesired waveguide modes will appear beyond the passband of the thru.

Device Fabrication Procedure
The device fabrication was performed in-house using standard laminate PCB processing. No special techniques or equipment are required for the build, eliminating unnecessary complexity and cost. To successfully plate the

blind signal via, the first three substrate layers were patterned using photolithography and laminated, then the signal via was drilled and plated. The rest of the stack-up was then laminated and all the through holes were drilled and plated. The via holes and air cavities were milled on a LPKF S103 milling machine. Half of the fabricated thru lines were designed for a probing station and the other half were designed to be used with Southwest Microwave edge launch connectors model 292-06A-5 [11]. The final fabricated devices are shown in Fig. 5.

Measured Results and Analysis
The fabricated devices are measured using a Keysight Technologies N5242A performance network analyzer.First, the S-Parameters of the thru are measured from DC-20 GHz. The measured insertion loss is less than 3.0 dB across the passband. The simulated and measured S_{21} are plotted together in Fig. 6. The measured return loss is greater than 10 dB across the passband. The simulated and measured S_{11} are compared in Fig. 7. Comparing the simulated and measured response, you can see that the measured response is shifted to

Simulated vs. Measured τ_g Comparison

Figure 8. Simulated vs measured group delay.

the left and the match at higher frequencies is degraded. However, the overall measured response shape is similar to the simulated response; therefore, we can deduce that the performance degradation is due to fabrication tolerances of the lines and spaces as well as alignment error.

Another very important parameter to be aware of is the group delay. For this technology to be useful in highly precise communications and radar systems, it is important that the design does not introduce any significant time delay, which can affect ranging to the target. The design should also have linear phase over the passband, or constant group delay, to ensure there is no dispersion, which could degrade the resolution cell [12]. The measured group delay is on average 0.2 ns. Assuming a signal traveling at the speed of light, this only adds 3 cm to the overall range. The simulated and measured group delay are plotted together in Fig. 8.

Overall, due to the acceptable and proven thru performance, the SISL technology is shown to be a viable option and further design modifications will be investigated.

Conclusions

In this paper, a DC-20 GHz suspended integrated strip-line thru structure, with a vertical via transition, was designed and implemented in a fully-integrated package inside a multi-layer board stack-up. Utilizing standard PCB processing techniques, the manufacturing complexity is kept to a minimum driving down the cost, while maintaining high repeatability. Another added benefit is the elimination of bulky connectors, due to the truly integrated metallized cavity design. The exceptionally low in-band insertion loss and minimal group delay potential, along with true integration and miniaturization, makes this an ideal design choice for high fidelity passive components. Due to the continued demand to decrease size, weight, and power (SWaP), this is an enabling technology for the high demands of future radar and communication systems. Lastly, this universal technology can be used to fully-integrate other passive microwave components such as gain equalizers, power dividers, and couplers, freeing up

valuable top copper real estate and reducing coupling between sensitive circuits.

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